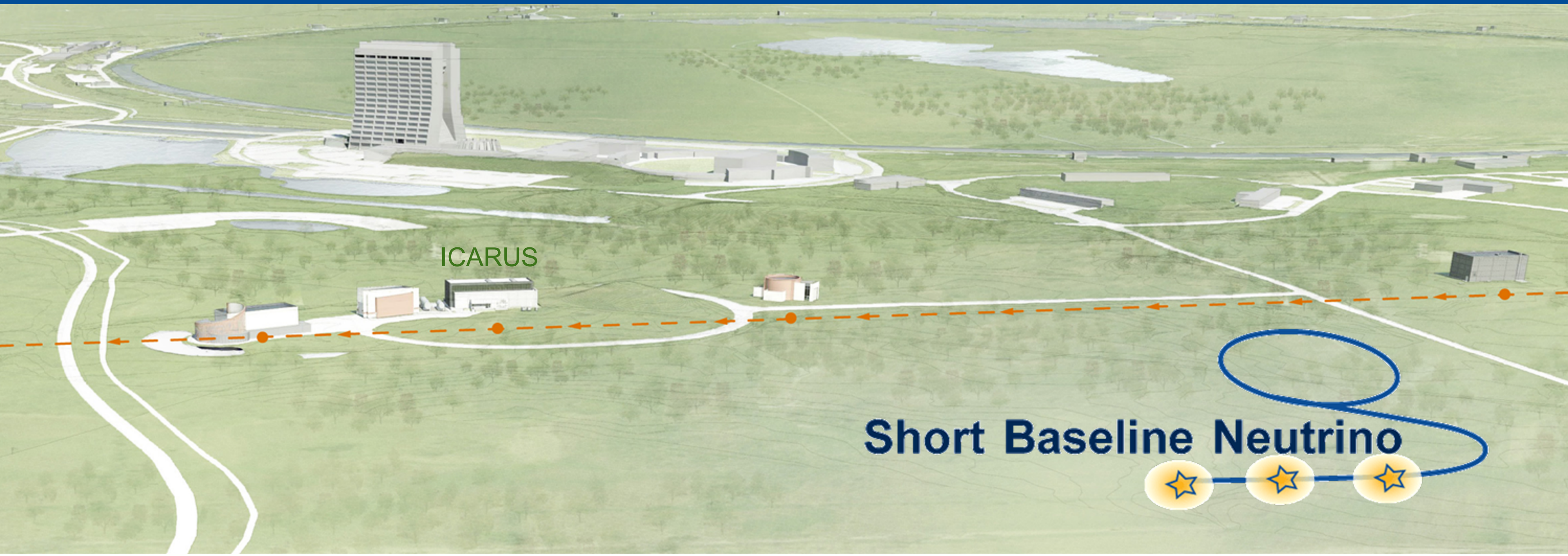
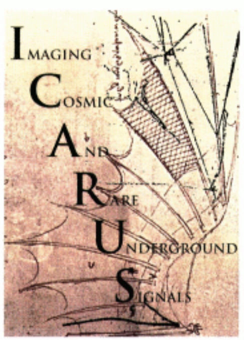


ICARUS@SBN Overview & Collaboration Management

Bob Wilson, Alberto Guglielmi

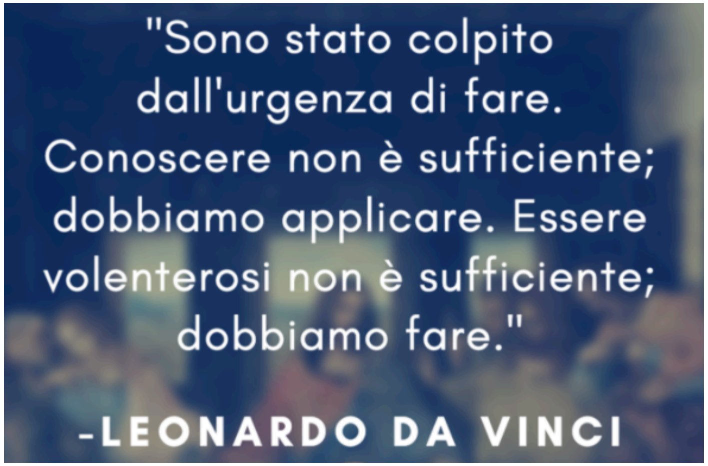
Operational Readiness Review

Dec 9-11, 2020



Outline

- Review context
- How we address the questions in the committee charge
- ICARUS collaboration
- Science goals
- ICARUS detector
- ICARUS collaboration organization
    - Detector Operations Group
    - Technical Board
    - Analysis and Software Group
- ICARUS Run Plan



- An adage to prepare for an experiment in the time of a pandemic
- There has been a tremendous amount of "doing" to get the experiment to this point
- This is an unusual year in so many ways
- … and preparing for an Operational Readiness Review while in the process of commissioning most of the detector, installing other parts, and with most of the collaboration unable to even visit the detector…is expressly unusual
- We will show that we are Ready to take commissioning data and we will be Ready for physics data when circumstance allow
- We look forward to your feedback and to working with Fermilab to make an exciting physics program a reality

Addressing the Charge Questions

We will update the EOP after feedback from this review

1. **Is there a completed Experiment Operations Plan (EOP) document?** The document should include
    a. an outline of the Science goals ***EOP Sec. 1, R.Wilson (this presentation)***
    b. a description of operations tasks and how they will be covered ***EOP Sec. 4, A.Fava/B.Howard (today)***
    c. a risk analysis that captures all known risks that will have a significant impact on the cost of operations, or the time needed to complete operations, with appropriate mitigation strategies. ***EOP Sec. 5, C.Montanari (today)***
    d. ES&H activities and how they will be managed ***EOP Sec 6.4, R.Wilson/C.Montanari (today)***
    e. organization charts showing the management structure for the program and how it interfaces with the laboratory ***EOP Sec. 4, R.Wilson (this presentation)***
    f. Fermilab resources and roles as they pertain to each Division ***EOP Sec. 6, A.Fava (tomorrow)***
    g. the model for data processing and analysis including the computing budget and effort required ***EOP Sec. 4.4, 6.3, W.Ketchum, T.Usher, D.Gibin, A.Fava***
    h. spares and maintenance needs ***EOP Sec. 4.1, 4.2, 6, 9 (Appendix B), C.Montanari***
    i. a list of the identified resources available ***EOP Sec. 6, 7, 8, 10, A.Guglielmi, A.Fava, C.Montanari, R.Wilson***
    j. a description of the roles and responsibilities of each institution together with a list of support required by each institution from funding agencies. ***Appendix A A.Guglielmi, A.Fava, R.Wilson***

Addressing the Charge Questions

2. Does the collaboration have an adequate plan for physics-quality data taking? If not, what modifications are needed to the current plan?
   Is there a clear plan for monitoring the beam and the data quality and has the associated infrastructure been tested? If not, what actions are required to adequately monitor the beam and the data quality?
   B. Howard, D. Torretta, W. Ketchum (today), M. Mooney (tomorrow)
3. Is there a well-understood run plan for FY21 through FY23, consistent with accelerator schedule and performance?
   R. Wilson (this presentation)
   Have adequate resources from the laboratory and the collaboration been identified for an efficient and safe running of the experiment and for maintenance of the detector, and is it clear who is responsible for what?
   C. Montanari (today), A. Fava (tomorrow)
4. Are there robust plans for data processing and data analysis? Have adequate resources from the laboratory and the collaboration been identified for data analysis to meet these goals?
   W. Ketchum (today), T. Usher, D. Gibin (tomorrow)
5. Are there clear goals set for reporting and publishing the results from the experiment in a timely fashion?
   D. Gibin (tomorrow)

Addressing the Charge Questions

5. Does the committee recommend further actions to ensure full exploitation of the SBN experimental program?
   We are interested to hear your ideas!

The ICARUS Collaboration

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C. Rubbia
INFN LNGS, Assergi (AQ), Italy
C. Vignoli
INFN LNS, Catania, Italy
S. Biagi, S. Cherubini, C. Distefano, R. Papaleo, G. Riccobene, P. Sapienza
INFN Sezione di Milano, Milano, Italy
N. Gallice, P. Sala, A. Zani
INFN Sezione di Milano Bicocca, Milano, Italy
R. Benocci, M. Bonesini, C. Brizzolari, A. Falcone, M. Spanu, F. Terranova, M. Torti
INFN Sezione di Napoli, Napoli, Italy
A. Cocco

The ICARUS Collaboration

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INFN Sezione di Pavia and University, Pavia, Italy
A. Menegolli, A. Rappoldi, G.L. Raselli, M. Rossella, A. Scaramelli
University of Pittsburgh, United States
A. Chatterjee, S. Dytman, B. Gomez Cortes, D. Naples, V. Paolone, L. Rice, M. Rosenberg, H. Su, N.B. Suarez
University of Rochester, United States
H. Budd, R. Howell, K.S. McFarland
SLAC National Accelerator Laboratory, United States
M. Convery, L. Domine, F. Drielsma, D.H. Koh, F. Garcia, G. Petrillo, H. Tanaka, K. Terao, Y.T. Tsai, T. Usher
Southern Methodist University, United States
T. Coan
University of Texas at Arlington, United States
J. Asaadi, H. Carranza, W. Jang, Z. Williams, J. Yu
Tufts University, United States
P. Abratenko, T. Wongjirad

The ICARUS collaboration consists of 150 scientists, engineers, and technical staff from 23 institutions

Spokesperson: **Carlo Rubbia**
Deputy Spokespersons:
Alberto Guglielmi, Robert J. Wilson
Institutional Board Chair: Mark Convery

[a] CERN, on leave of absence from Padova
[b] Fermilab, on leave of absence from Pavia

With contributions from INFN Sezione di Lecce and University of Salento

Science Goals

- The primary science goal of the experiment, in association with the SBND detector, is a search for evidence of eV-scale sterile neutrinos by the simultaneous measurement of the rate of muon-neutrinos and electron-neutrinos in the BNB
  - Early Physics: With ICARUS alone, using both BNB and NuMI neutrinos, we will look for evidence for higher-mass scale sterile neutrinos (~7 eV^2) exhibiting flavor oscillations on much shorter distance scales (observed by the Neutrino-4 reactor experiment)

Program Advisory Committee 7 Dec. 2020
https://indico.fnal.gov/event/46083/

- Perform a search for evidence of dark matter candidates produced in NuMI target
- Perform cross section measurements and reconstruction studies of multi-GeV neutrinos produced in the NuMI target

More details in backup.

ICARUS-T600 at Gran Sasso Underground Laboratory

- Two identical modules (T300) each is 19.6 x 3.6 x 3.9 m^3
- ICARUS-T600 Liquid argon mass: total 760 t; active 476 t
- Drift distance 1.5 m. Electric field 500 V/cm (75 kV) -> drift time ~1 ms
- 3 signal wire planes (2 induction + 1 collection)
- Pitch and inter-plane distances: 3 mm; 400 ns sampling time
- ~54,000 channels

Journey of ICARUS from Gran Sasso to CERN

2014

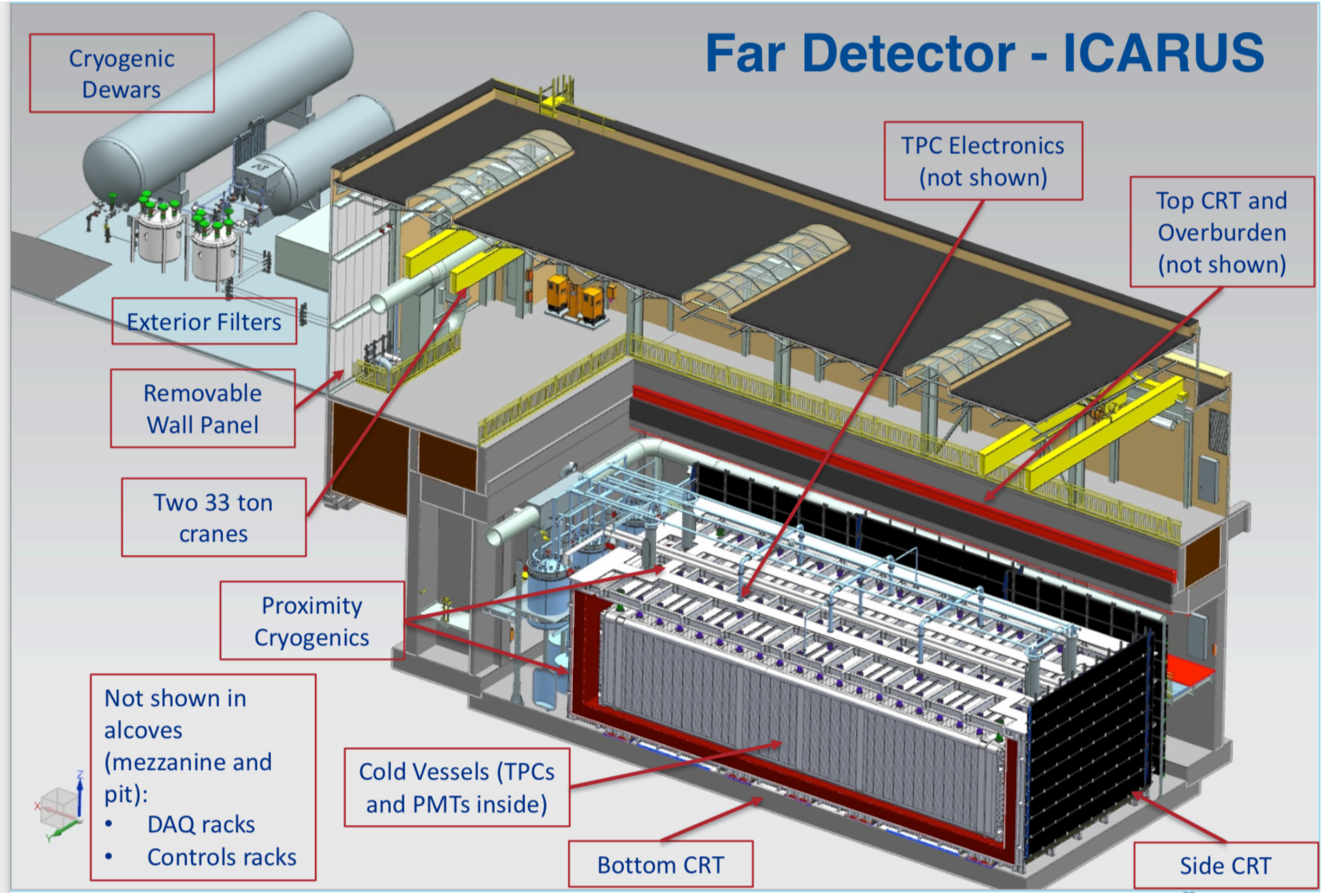
Journey of ICARUS from CERN to Fermilab

Departing CERN on June 12,2017

Antwerp, Belgium loading to ship to Burns Harbor (Indiana, US)

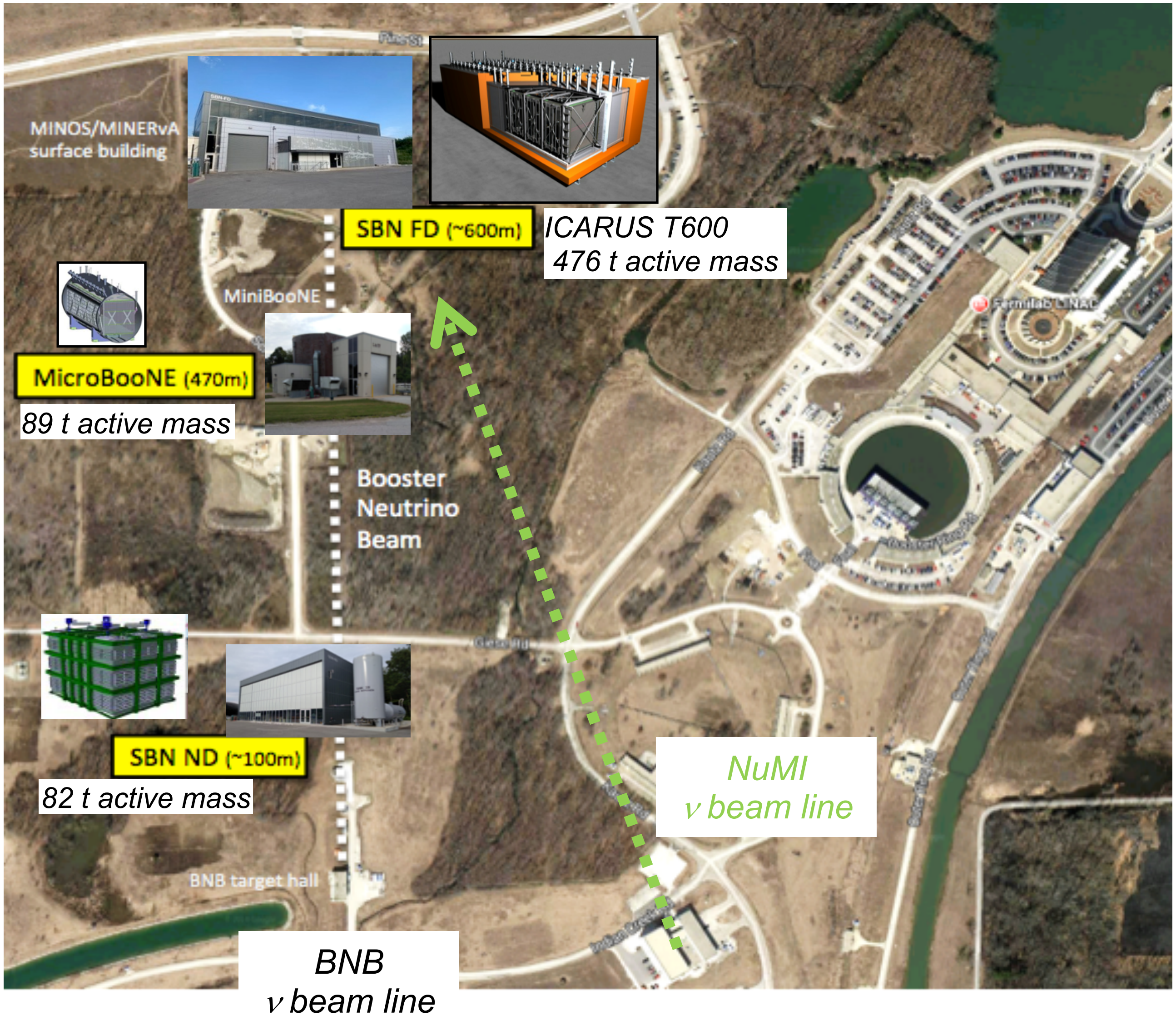
Arriving at FNAL SBN, July 26,2017

To its final home at SBN



Far Detector - ICARUS
Cryogenic Dewars
TPC Electronics (not shown)
Top CRT and Overburden (not shown)
Exterior Filters
Removable Wall Panel
Two 33 ton cranes
Proximity Cryogenics
Not shown in alcoves (mezzanine and pit):
• DAQ racks
• Controls racks
Cold Vessels (TPCs and PMTs inside)
Bottom CRT
Side CRT

Neutrino Beam Layout at Fermilab



Collaboration Management

Institutional Board
Chair: M. Convery (SLAC)

Editorial & Speakers Board
Chair: A. Menegolli (INFN-Pavia)

Executive Committee
Spokesperson
C. Rubbia (GSSI)
Dep. Spokespersons
A. Guglielmi (INFN-Padova),
R. Wilson (CSU)
Institutional Board Chair
Others as appointed by the Spokesperson:
Technical Coordinator,
Commissioner,
Analysis Coordinator, etc.

SBN Oversight Board
Chair: S. Brice (FNAL)

C. Rubbia
A. Guglielmi
R. Wilson

Detector Operations
Run Coordinator
A. Scarpelli (BNL)
Dep. Run Coordinator (tbd)
Operations Support Manager
H. Budd (UR)
Technical Coordinator
C. Montanari (FNAL/Pavia)
Experiment Liaison Officer
Carrie McGivern (FNAL)

Technical Board
Technical Coordinator
C. Montanari
(FNAL/INFN-Pavia)
Dep. Tech. Coord.
A. Fava (FNAL)

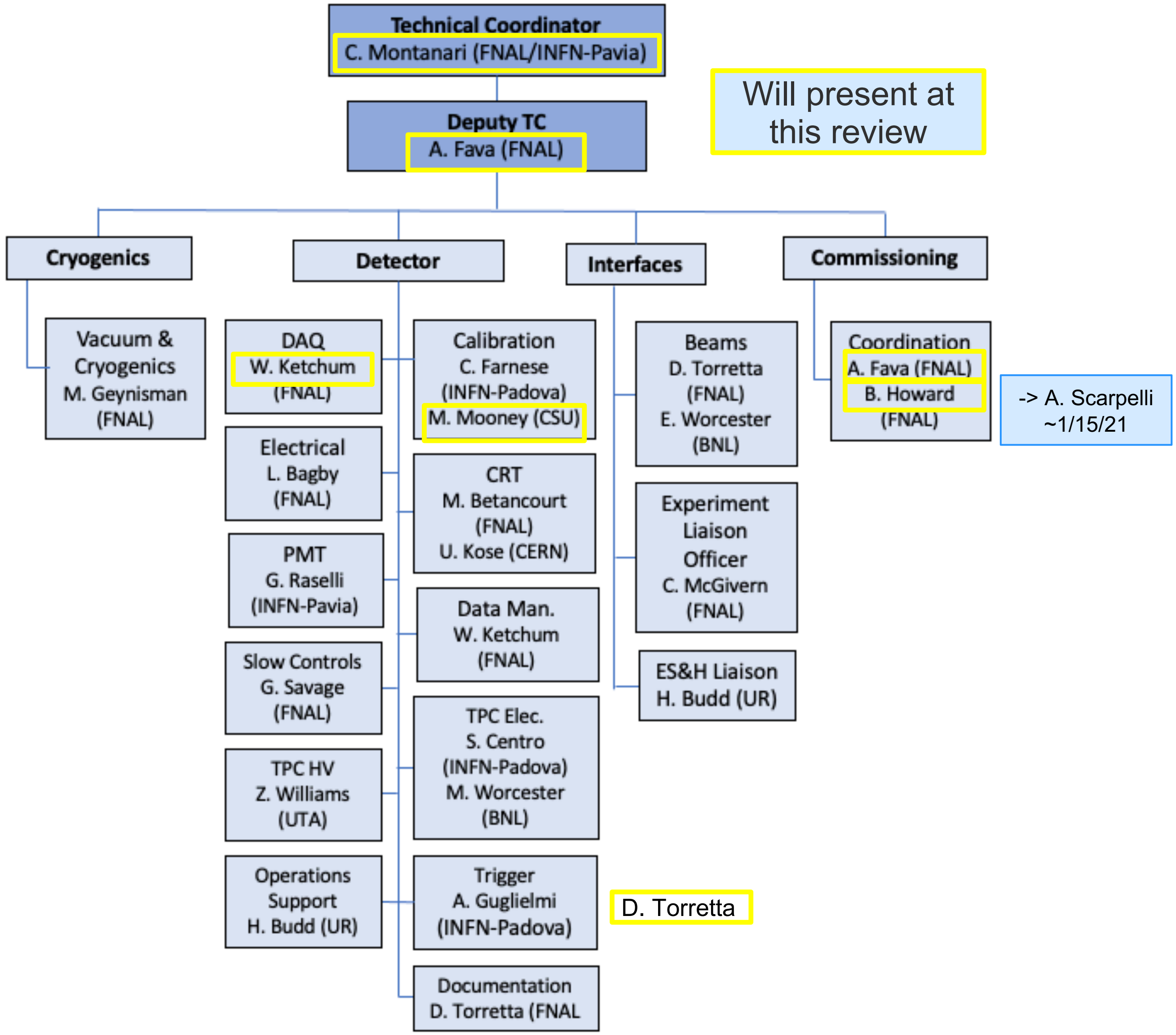
ES&H Division Safety Office
Division Safety Officer
A. Aparicio (FNAL)

Analysis & Software
D. Gibin (INFN-Padova) - Phys. Anal. Coord.,
T. Usher (SLAC)

Towards Detector Operations

- **Installation:** The Technical Coordinator (C. Montanari/FNAL) and Deputy TC (A. Fava/FNAL) worked with the FNAL SBN Project team (led by P. Wilson & C. James) to oversee all installation activities
- **Commissioning:** After most installation was completed A. Fava became ICARUS Commissioner with B. Howard as Deputy Commissioner
  - TC will coordinate installation of final CRT components and major repairs and maintenance
- A. Scarpelli (BNL) will move to Fermilab to become Deputy Commissioner in January then will become the first Run Coordinator in the spring
  - Exactly when will depend on progress with commissioning, which depends on access to the detector especially from European collaborators

Collaboration Management – Technical Board



Detector Operations Group

Run Coordinator (RunCo)

- is charged with optimizing the safe operation of the ICARUS detector to meet the physics goals
- will direct and decide the priority and scheduling of detector systems development and maintenance (in consultation with TC)
- has responsibility for maintaining shift procedures and maintaining the systems expert on-call list. [A Shift Manager (D. Mendez) is the shift scheduler]
- will be the primary contact between the experiment and the Fermilab Main Control Room and will be responsible for reports at the All-Experimenters' Meeting

- will generally serve in this position for two-three months (tbd). A Deputy Run Coordinator will work with the RunCo for three months then take over as RunCo

Detector Operations Group

Operation Support Manager (OSM)

- oversees efforts to improve the efficiency and safety of of detector operations
- provides continuity for operations procedures across the relatively short terms of the Run Coordinators
- is the safety point-of-contact for the collaboration and works with the DSO and ELO to develop safety procedures for ICARUS operations consistent with Fermilab safety rules
- will assist collaborators in following the safety procedures, and will update the Individual Training Needs Assessments (ITNA)

Detector Operations Group

Technical Coordinator (TC)

- oversight and coordination for all ICARUS detector systems installation activities
- primary collaboration technical contact with SBN Project Director and Fermilab installation team
- chair of the Technical Board
- ensures that the detector working groups (DWG) are working effectively and responding quickly to system failures that impact efficient detector operations
- consults with Deputy Spokespersons on resource and personnel issues

Experiment Liaison Officer (ELO)

- serves as a line of communication between the ICARUS Collaboration and the Fermilab operations support groups inside the Neutrino Division, and the Accelerator and Particle Physics Divisions
- is charged with identifying the resource needs for operation, maintenance, and repair of equipment required for ICARUS operations and working with the collaboration to find the necessary resources

Collaboration Management – Analysis & Software

Analysis and Software Coordination
D. Gibin (INFN-Padova),
T. Usher (SLAC)

SBN Joint Working Groups
D. Gibin (INFN-Padova),
O. Palamara (FNAL)

Infrastructure

- Software Releases
  T. Usher (SLAC)
- Data Production
  M. Wospakrik (FNAL)
  F. Drielsma (SLAC)
- Database Management
  (tbd)
- Detector Description
  A. Menegolli (Pavia)
  M. Torti (MIB)

Simulation/Reconstruction

- Cosmic Ray Tracker
  U. Kose (CERN)
  B. Behera (CSU)
- TPC Track/Shower
  B. Howard (FNAL)
  F. Varanini (Padova)
- Light System
  G. Petrillo (SLAC)
  K. Terao (SLAC)
- TPC Signal Processing
  F. Varanini (Padova)
  T. Usher (SLAC)
- Trigger
  G. Petrillo (SLAC)

Tools

- Event Filter
  D. Gibin
  (INFN-Padova)
- Neutrino Selection
  C. Farnese (Padova)
- Calibration
  C. Farnese (Padova)
  M. Mooney (CSU)
- Event Display
  (M. Del Tutto (FNAL))
  T. Usher (SLAC)
- Beam Simulation
  (tbd)

Analysis

- SBN Oscillation
  D. Gibin (Padova)
- Neutrino4 Oscillation
  D. Gibin (Padova)
- NuMI Cross Sections
  M. Betancourt (FNAL)
- NuMI Dark Matter
  A. Chatterjee (UP)

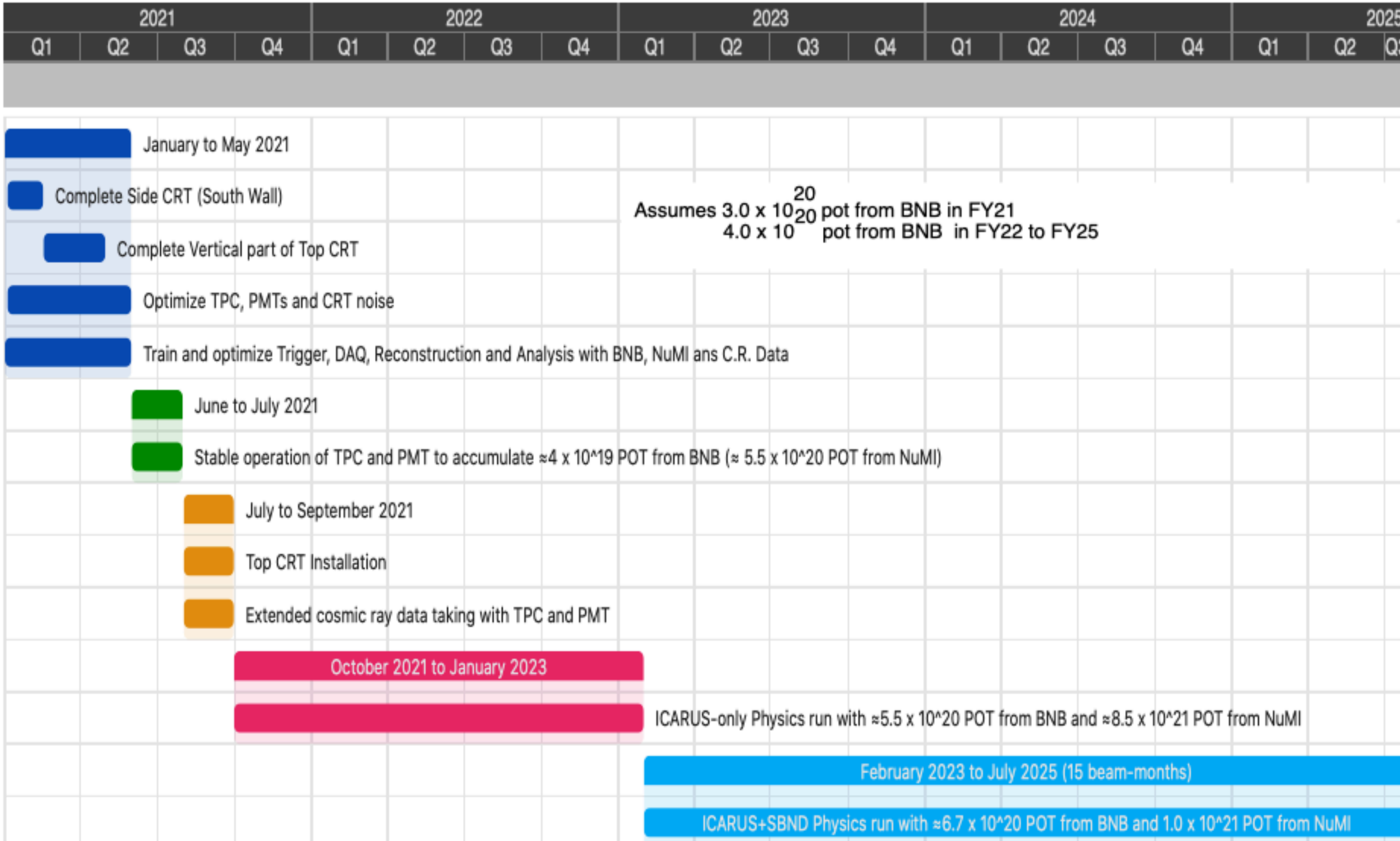
ICARUS Run Plan

- To reach 5σ sensitivity of the LSND allowed (99% C.L.) region for $\nu_\mu \rightarrow \nu_e$ appearance, the SBN program requires an exposure of **6.6×10^{20}** protons on target (POT) in the Booster Neutrino Beam for the SBND and ICARUS detectors
- Projections for BNB performance* indicate delivery of ~3.0×10^{20} POT in FY21 and 4.0×10^{20} POT/yr in each of FY22-FY25
- The experiment will also perform neutrino cross section measurements and dark matter search off-axis from the NuMI beam target with a nominal ~6.0×10^{21} POT/yr exposure
- Confirmation of the Neutrino-4 result is an important new addition to the physics program that can be achieved within the first year of operation with the complete detector
- ICARUS anticipates completion of the detector (full CRT and overburden) in summer 2021. The SBND S-4b ready-for-physics data milestone forecast date is January 2023**

*T. Kobilarcik, presentation at the Dec. 2019 SBN Oversight Board Meeting
** Near Detector Key and Intermediate Milestones Oct. 2020 SBN Review

ICARUS Run Plan – 2021 - 25

Text version in the backup



A revised AD plan is on the horizon – it would extend BNB running by 15 mths

Questions?

Backups

ICARUS Run Plan

With these assumptions (subject to modifications due to COVID restrictions) the ICARUS run plan is as follows:

- **January 2021 – May 2021** [Side CRT and vertical Top CRT installation complete. Install new cryogenic filter system. Commission TPC electronics and Trigger.] Take neutrino data from BNB and NuMI for trigger, calibration, reconstruction software and analysis development.
- **June 2021 – July 2021** Maintain stable operation of TPC and PMT system to accumulate neutrino data for ~4.0 x 10^{19} POT from BNB (~5.5 x 10^{20} POT from NuMI).
- **July 2021 – September 2021** [Top CRT installation.] Extended cosmic ray data taking with TPC and PMT.
- **October 2021 – January 2023** (13 beam-months) ICARUS-only Physics run with ~5.5 x 10^{20} POT from BNB and ~8.5 x 10^{21} POT from NuMI.
- **February 2023 – July 2025** (15 beam-months) ICARUS+SBND Physics run with ~6.7 x 10^{20} POT from BNB (~10.0 x 10^{20} POT from NuMI).

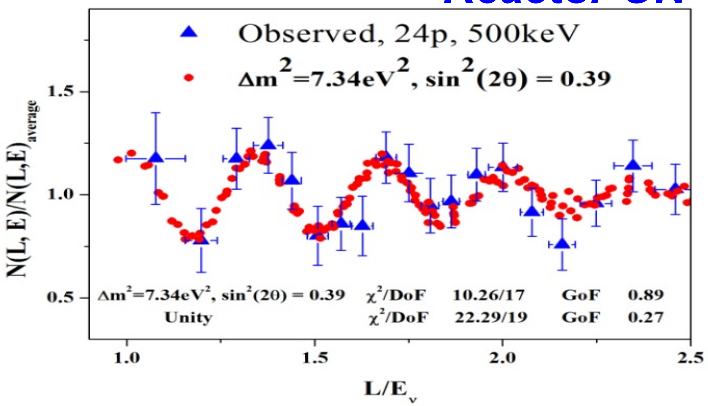
- A revised AD plan is on the horizon – would extend BNB running by 15 mths

Neutrino-4 Experiment

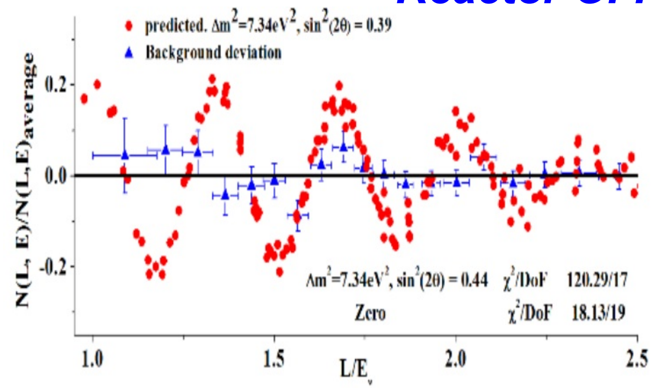
The NEUTRINO-4 reactor experiment has recently presented a new and remarkable result with the first direct experimental observation of neutrino produced oscillations by an additional sterile neutrino, due to disappearance in the positron + neutron channel as a function of L/E, with L the distance travelled (m) and E energy (MeV) of the incoming νe.

With NEUTRINO-4 the hypothesis of oscillation is verified by direct measurements with a movable and spectrum sensitive detector of the anti-ν flux and energy spectrum vs. distance near a Reactor core.

Reactor ON



Reactor OFF



- The obtained value of the difference between the masses of the electron and sterile neutrinos is $\Delta m_{14}^2 = 7.26 \pm 0.13$ stat $\pm$ 1.08 syst eV^2 and the angle θ_{14} parameter $\sin^2(2\theta_{14}) = 0.26 \pm 0.08$ stat $\pm$ 0.05 syst. Lower probability satellite peaks are also observed at other masses.

R. Wilson I ICARUS Overview

Early physics programs

- We are proposing an alternate option for initial data taking to be initiated approximately by the beginning of next year already with the partial ICARUS configuration in place, awaiting the SBND startup .
- A number of persistent neutrino related anomalies have been recorded during several decades. In particular: the anti ν–e appearance from anti-$\nu\mu$ beam in the accelerator LSND [1] experiment; the ν–e disappearance by SAGE [2] experiment; (observed/predicted rate R = 0.84±0.05); the GALLEX [3] experiment during its calibration with Mega-Curie source; and the anti ν–e disappearance of near-by Nuclear Reactor [4] experiments (R = 0.934±0.024).
- The main goal of this investigation will be the definitive verification with ICARUS of the recent observation of sterile neutrino oscillations claimed by the NEUTRINO-4 experiment.
- NuMI beam will allow ICARUS to measure with high statistics ν-e cross-section. In addition, ICARUS would perform accelerator-based dark matter searches with BNB and NuMI beams (see backup slides).

The NEUTRINO-4 experiment

- The NEUTRINO-4 reactor experiment has recently presented a new and remarkable result with the first direct experimental observation of neutrino produced oscillations by an additional sterile neutrino, due to disappearance in the positron + neutron channel as a function of L/E, with L the distance travelled (m) and E energy (MeV) of the incoming ν-e.
- With NEUTRINO-4 the hypothesis of oscillation is verified by direct measurements with a movable and spectrum sensitive detector of the anti-neutrino flux and energy spectrum vs. distance near a Reactor core.
- To detect oscillations to a sterile state, one observes a deviation of flux-distance relation from $1/L^2$ dependence and of alterations of the form of energy spectrum with distance.
- This search may be clarified by ICARUS in a few months of data taking, before the completion of the detector upgrade and of the joint operation planned with the SBND detector.

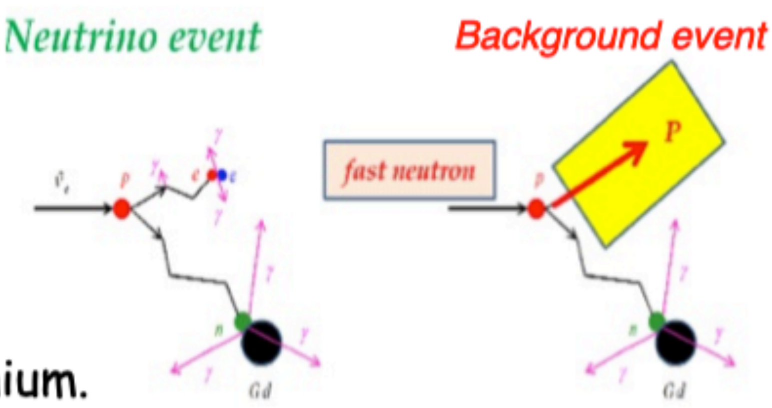
The NEUTRINO-4 set-up

- NEUTRINO-4 is based on a very compact Reactor core of 35 x 42 x 42 cm^3 and 90 MW power. The distance from the core is 5 m and measurements of the anti-neutrino flux are observed in the range of 6 to 12 m.
- At 8 m distance from the Reactor, ~ 300 anti ν-e events/day with 1 m^3 of liquid scintillator are recorded. At a typical 9 m distance from the core, the anti-ν energy is 9 MeV for L/E = 1 and 3.6 MeV for L/E = 2.5. The reaction is fitted as

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{14} \sin^2\left(1.27 \frac{\Delta m^2_{14}[eV^2]L[m]}{E_{\bar{\nu}}[MeV]}\right)$$

where Eν is anti-ν energy in MeV, L the distance in meters, Δm_{14}^2 is difference in eV^2 between squared masses of electron and sterile νs, θ_{14} the mixing angle between electron and sterile neutrinos.

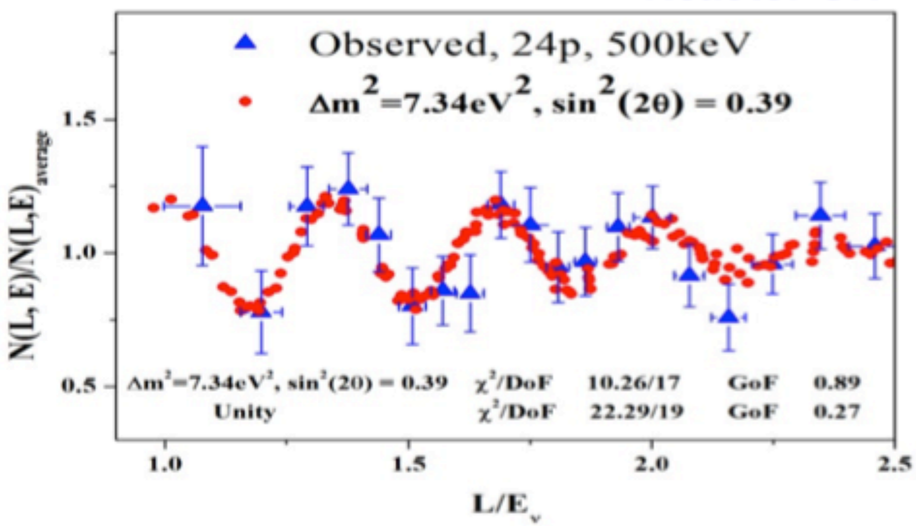
- The anti-νe signal by anti ν-e + p -> e+ + n is e+ and a delayed neutron captured by 0.1 % gadolinium added to liquid scintillator.
- Fast ns emitted in interactions of high energy cosmic μs with matter around the detector are the main background by n + p -> p + n with n also captured by gadolinium.



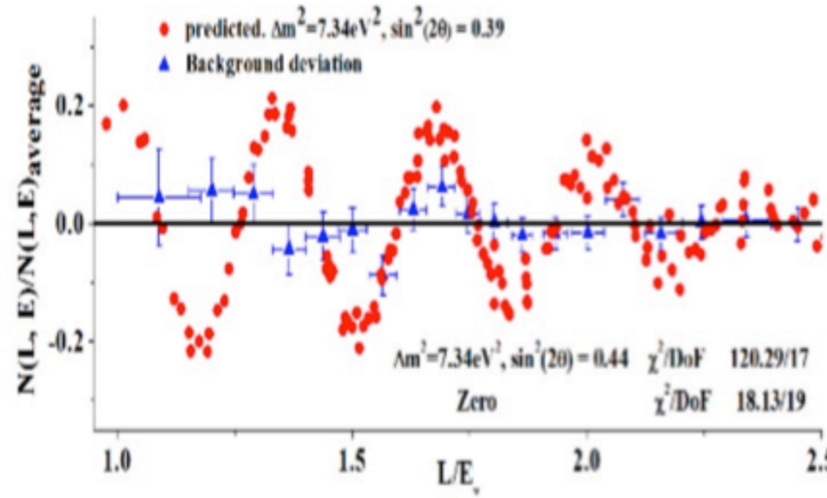
NEUTRINO-4 reactor signal

- Data has been collected for 3 years until June 2019, followed by background measurements until January 2020: 720 days reactor "on" and 417 days reactor "off", with 87 reactor cycles.

Reactor ON



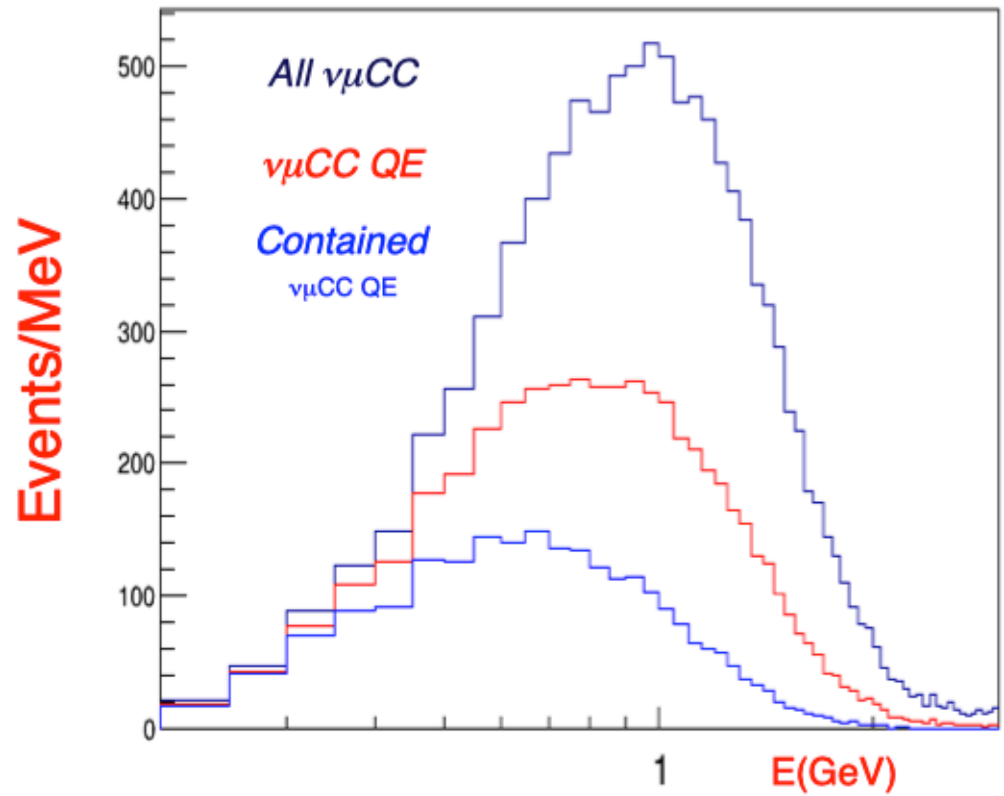
Reactor OFF



- The difference ON-OFF is 223 events per day in the range from 6.5 to 9 meters. The signal/background ratio is 0.54
- The obtained value of the difference between the masses of the electron and sterile neutrinos is Δm_{14}^2 = 7.26 ± 0.13 stat ± 1.08 syst => 7.25 ± 1.09 eV^2 and the angle θ_{14} parameter $\sin^2(2\theta_{14})$ = 0.26 ± 0.08 stat ± 0.05 syst => 0.26 ± 0.09. Lower probability satellite peaks are also observed at other masses.

Expected Booster rates

- ~560'000 $\nu\mu$–CC events, corresponding to $6.6*10^{20}$ pot in 3 years and the ICARUS active volume
- The μCC-QE interactions are ~49% of all charged current events.
- Requiring the event to be contained within the ICARUS active volume guarantees a better reconstruction resulting in ~118'000 collected events .

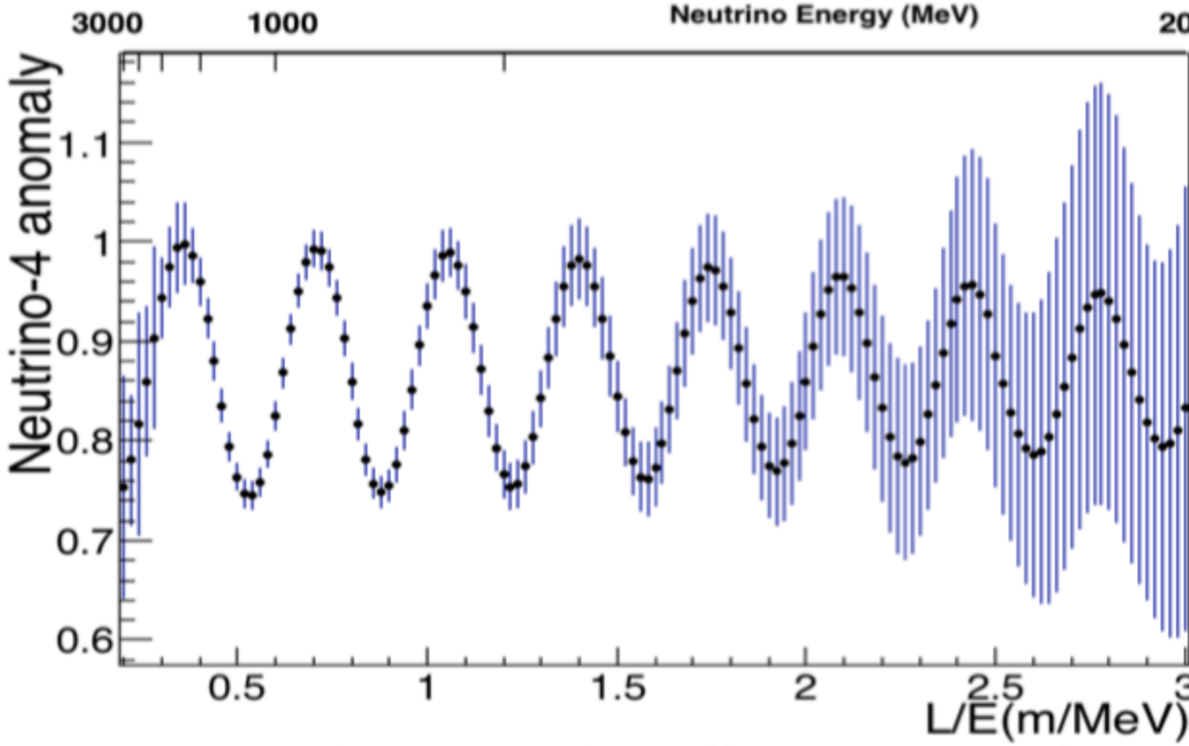


νμCC: ~ 560'000 events
νμCC QE: ~270'000 events
Contained νμCCQE: ~118'000 events
(~ 350 beam ev/day)

Expected NUMI rates

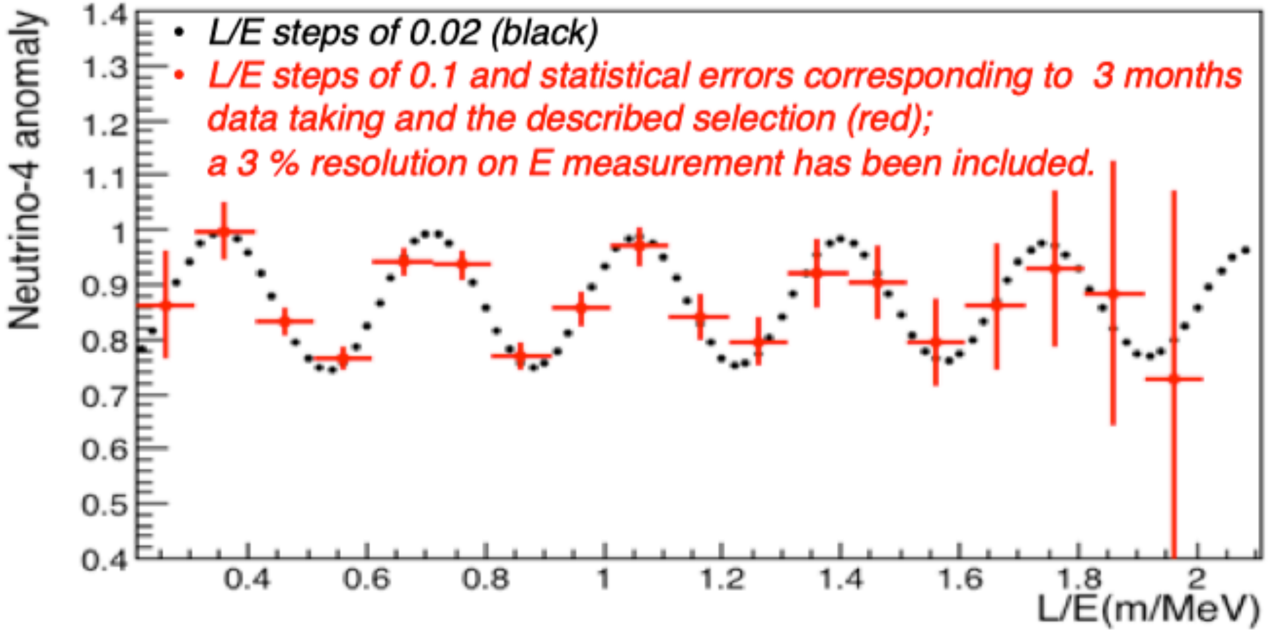
- The NUMI off-axis proton beam is located at ~700 m from ICARUS and at an off-axis angle of 6 degrees. One year with 0.75 Hz NUMI repetition rate and spills of 6×10^{13} ppp corresponds to a 6×10^{20} pot exposure. For positive (negative) focussing we expect 4.3×10^5 *CC* events/y (~3.7×10^5 *CC* evs/y).
- The ratio (ν-e *CC*)/(ν-μ *CC*) = 4.8 % for positive focusing and about 40% are quasi-elastic (QE).
- NUMI rates correspond to one *CC* event each 23 spills for positive focussing (one *CC* event each 26 spills in negative focussing).
- Although the ν−μ from NUMI can also be analysed, kaons are primary goal in the off-axis NUMI, leading to a much larger participation of the ν−e signal and with a neutrino energy distribution similar to the Booster beam case.

Booster after 3 years and for NEUTRINO-4 prediction



- The figure represents the survival oscillation probability in the presence of the Neutrino-4 anomaly.
- The calculation has been performed considering a 3 years long run (~117k $\nu\mu$CC QE contained events) for steps of delta(L/E) = 0.02 and considering the best fit of NEUTRINO-4 parameters $\Delta m^2_{N4}=7.25\ eV^2$ and $\sin^2 2\theta_{N4}=0.26$ (only statistical errors are reported).

Results in 3 months, adding Lμ > 50 cm & expected energy resolution



- The performed study on the trigger shows a total reduction of ~3% on ν_μCC QE contained events concentrated at low Eν increasing the statistical uncertainty at high L/E values.
- Additional request on the muon length L_μ > 50 cm for a better μ identification has been also included resulting in ~11500 events in 3 months data taking.
- As a first approximation ~3% smearing on E has been applied (a resolution better than 1% is expected for μs which take ~70% of the ν energy).
  As shown in the plot, the oscillation pattern is not spoiled when the precision on reconstructed Eν for contained ν_μCC QE events is accounted for.

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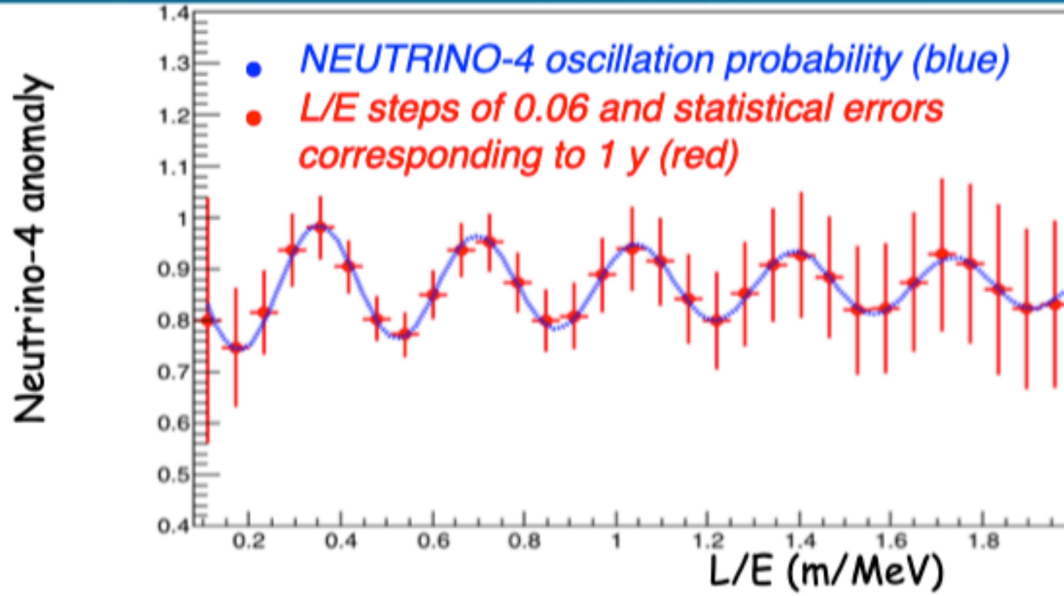
Short Baseline Neutrino

Result after 1 year in NuMI and for NEUTRINO-4 prediction

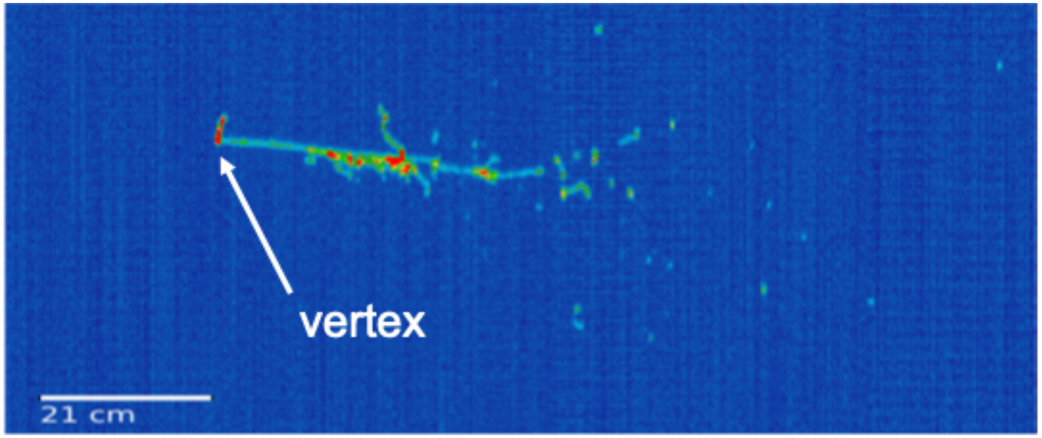


- The survival oscillation probability in the presence of the Neutrino-4 anomaly is shown considering a 1 year data taking (~5200 νeCC QE) for the best fit of NEUTRINO-4 parameters $\Delta m^2_{N4}=7.25\ eV^2$ and $\sin^2 2\theta_{N4}=0.26$. Only statistical errors are reported, effects of energy reconstruction are expected marginal, given the optimal ICARUS energy resolution for e- and e.m. showers.
- Despite the 725 m long NuMI decay tunnel most of νe are produced by kaons decaying close to target. The residual variations of the distance travelled by νs do not wash out the characteristic Neutrino-4 oscillatory pattern.

Off-Axis NuMI beam at ICARUS

- ICARUS detector is located 103 mrad off-axis to the NuMI beamline and provides additional source for neutrino and dark matter candidates.
- **SBN Readiness**: Electron neutrino spectra from NuMI and Booster are very similar - using NuMI as a source will allow high statistics measurements in a similar energy range before the two-detector SBN oscillation program begins.
- **DUNE**: There are no high statistics measurements of νe cross-section and muon neutrino to electron neutrino ratio cross section on argon at DUNE energies. Off-axis NuMI provides high statistics in this energy range.
- **Dark Matter**: Direct-Detection Dark Matter search experiments have ~GeV threshold limit. Recent theoretical work has motivated accelerator-based dark matter searches in an interesting mass range accessible with BNB and NuMI.

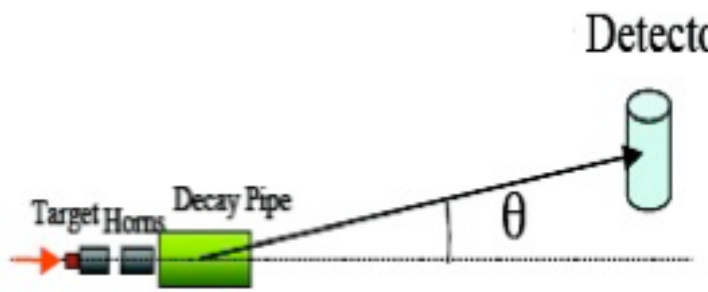
Simulated NuMI ν_e with an electron shower



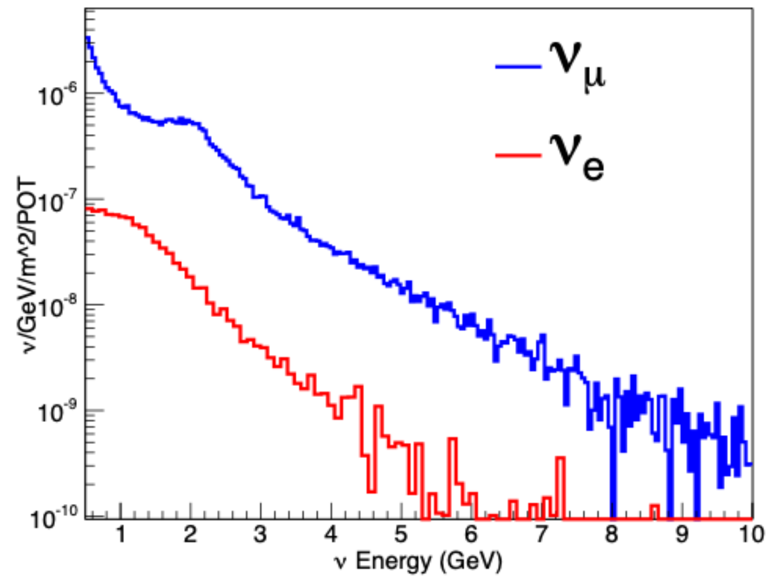
R. Wilson I ICARUS Overview

Off-Axis NuMI beam at ICARUS

ICARUS is 103 mrad off axis from the NuMI beam



$$E_\nu = \frac{0.43 E_\pi}{1+\gamma^2\theta^2}$$

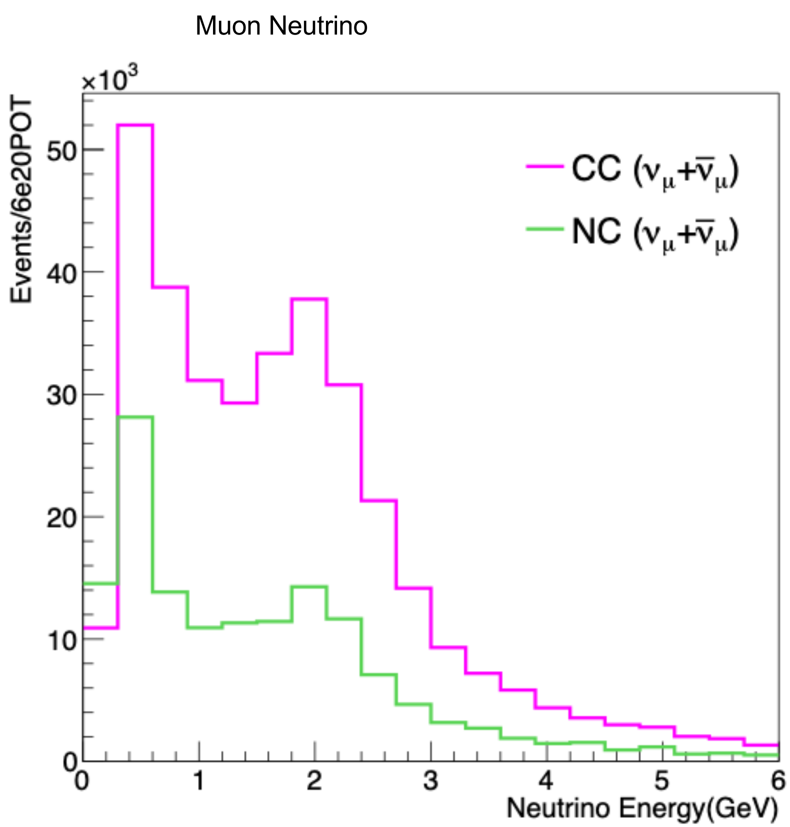


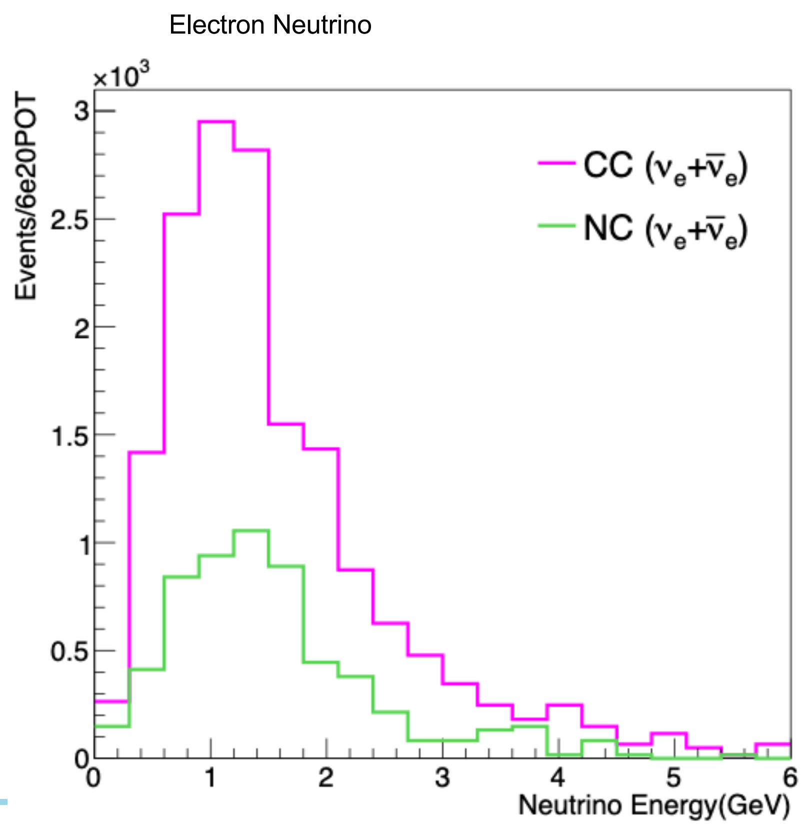
- 1 neutrino interaction every 15 spills; 6x 10^{20} POT per year
- FY21 run plan is with neutrinos; NOvA might switch to antineutrinos in FY22 or FY23
- High statistics for muon and electron neutrinos at ICARUS from NuMI beam

Neutrino Interactions from NuMI off axis

Requiring neutrino interaction vertices in the active LArTPC volume
Predicted events per year (6e20 POT) in ICARUS:

- CC muon neutrino = 4.3×10^5, NC muon neutrino = 1.9×10^5
- CC electron neutrino = 2.0×10^4, NC electron neutrino = 7.3×10^3





Short Baseline Neutrino

Status

Event selection:

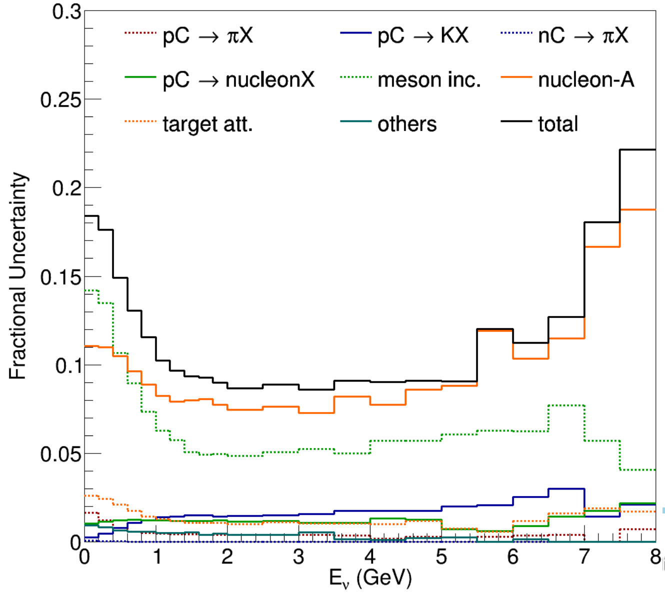
- Improving reconstruction tools, better vertex finding and shower energy
- Electron neutrino and muon neutrino event selection studies in progress
- Backgrounds for inclusive cross section analyses: cosmic rays and neutral current events
- Starting to investigate different techniques to reject the cosmic background without the full CRT

Using reconstructed information from the TPC, 72% of cosmic background is removed; side and bottom CRT could be used to remove 20% of the cosmics

Developing cosmic rejection using the PMT system

Understanding the neutrino flux using constrained flux simulation from the MINERvA experiment

Uncertainties for Electron Neutrino



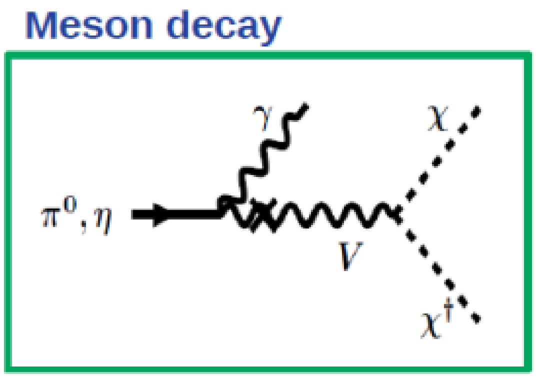
Dark Matter Search @ICARUS using NuMI

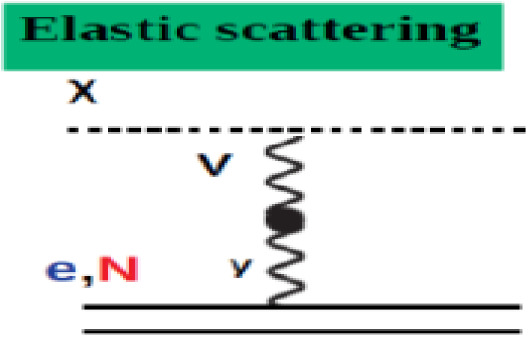
• Models of sub-GeV dark matter typically involve scalar or fermion DM "mixes" with SM through vector or scalar mediators (Vector Portal/Higgs Portal)

• DM Production: DM produced in neutral hadrons
DM Detection: DM-electron scattering
as the outgoing electron will be very forward

• Background: Any process with a final state electron

• CRT will be very useful for reducing cosmic background and for other cosmogenic dark matter search
• Combination of side CRT and PMT information can be useful for background rejection





Status

- Sub-GeV DM events are generated using 120 GeV NuMI Beam with 10^{21} POT
- Angular cut (0.100±0.002) mrad to select events that enter the detector
- Scattered electron with cos(theta) >=0.99 selected as signal
- Preliminary sensitivity result looks promising: 2 years of data taking can explore large parameters of DM.
- Detector simulation of signal and background in progress
- Design of trigger for signal selection (NC events) in progress